

# Young radio sources: the duty-cycle of the radio emission and prospects for gamma-ray emission

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The evolutionary stage of a powerful radio source originated by an AGN is related to its linear size. In this context, compact symmetric objects (CSOs), which are powerful and intrinsically small objects, should represent the young stage in the individual radio source life. However, the fraction of young radio sources in flux density-limited samples is much higher than what expected from the number counts of large radio sources. This indicates that a significant fraction of young radio sources does not develop to the classical Fanaroff-Riley radio galaxies, suggesting an intermittent jet activity. As the radio jets are expanding within the dense and inhomogeneous interstellar medium, the ambient may play a role in the jet growth, for example slowing down or even disrupting its expansion when a jet-cloud interaction takes place. Moreover, this environment may provide the thermal seed photons that scattered by the lobes' electrons may be responsible for high energy emission, detectable by *Fermi*-LAT.

## 1. Introduction

It is nowadays clear that powerful ( $L_{1.4\text{GHz}} > 10^{25}$  W/Hz) radio sources are a small fraction of the Active Galactic Nuclei (AGN) generally associated with ellipticals, suggesting that the radio activity is a transient phase in the life of these systems. The onset of radio emission is currently thought to be related to mergers which provide fuel to the central AGN. The evolutionary stages of a powerful radio source are related to its linear size. The discovery of the population of intrinsically compact and powerful radio sources, known as compact symmetric objects (CSOs), yielded to an improvement of the models proposed to link the various evolutionary stages of the radio emission. CSOs are characterized by linear sizes up to a few kpc, and a synchrotron spectrum that turns over between hundreds of MHz and the GHz regime. Their genuine youth has been proved by estimate of both kinematic and radiative ages, which result to be  $\sim 10^3$ - $10^4$  years [12, 17]. Their radio morphology is dominated by mini-lobes/hotspots resembling a scaled-down version of the classical edge-brightened Fanaroff-Riley type-II galaxies [6]. Following the evolutionary models [e.g. 7] CSOs should be the progenitors of the "old" FR II galaxies. However, the excess of young objects in flux-limited samples suggests the existence of short-lived objects unable to become FR II, and additional ingredients, like the recurrence of the radio emission [5], or the interplay between the source and the environment, must be considered. Indeed, the dense and inhomogeneous medium left by the merger that triggered the radio emission may play a role in the source growth, for example slowing down or even disrupting the jet expansion [3]. Given their compact size, CSOs entirely reside within

the innermost region of the host galaxy. In the most compact radio sources, the radio lobes are only a few parsecs from the AGN and their relativistic electrons can scatter the thermal UV/IR seed photons produced by both the accretion disc and the torus, up to high energies. For this reason, high energy  $\gamma$ -ray emission detectable by *Fermi*-LAT is expected from these compact objects.

## 2. The duty-cycle of the radio emission

When the sub-arcsecond morphology of compact symmetric objects could be investigated by the advent of high spatial resolution observations, it resulted to be characterized by the same structures typical of the classical FR II galaxies, but on much smaller scale. For this reason, [16] suggested that CSOs should be objects whose radio emission is still in a young phase of its evolution. Following this approach, the fate of CSOs is to evolve into the FR II. However, the number counts of young objects is too high with respect to those of the "old" radio galaxies in flux-limited samples, even when a luminosity evolution is taking into consideration. The discovery of kpc-scale low-surface brightness structures, likely the fossil of an old episode of radio emission, and connected with young radio galaxies (i.e. J0111+3906,[4]) suggests that the radio activity may be a recurrent phenomenon in the lifetime of a galaxy. Furthermore, relics of previous activities have been recently found also on pc-scales close to newly born objects indicating that the radio activity may be also short-lived. This implies that the time elapsed between two subsequent periods of radio activity can be as short as a few thousand

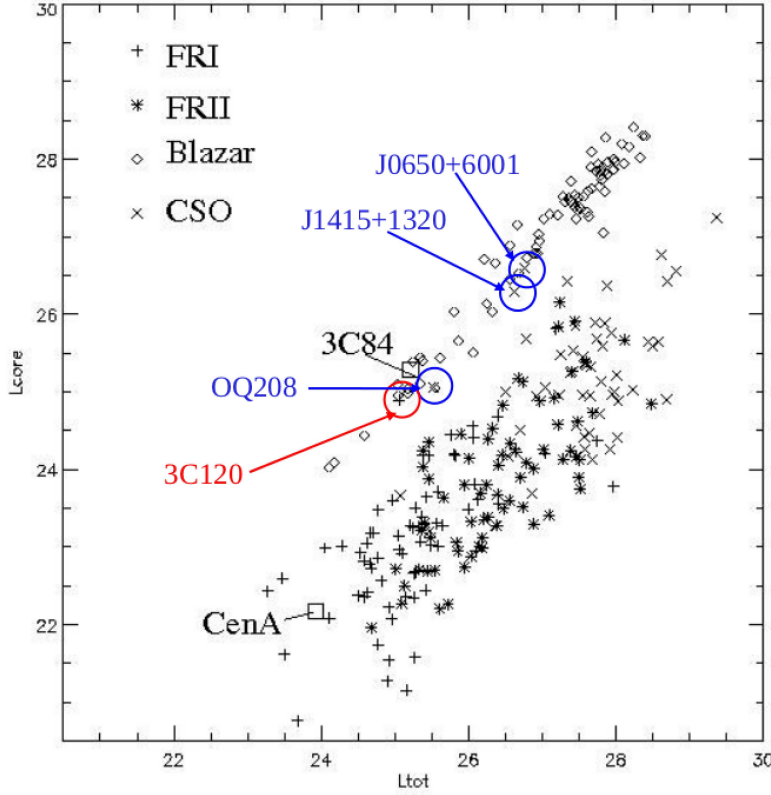


Figure 1: Total luminosity ( $x$ -axis) vs core luminosity ( $y$ -axis) of a sample of FRI (+ signs) and FR II (asterisks) radio galaxies from [9], blazars (diamonds), and CSOs (x symbols). LBAS blazars are from [10].

years (e.g. J1511+0518, [13]), as also predicted by the models (e.g. [5]). The radio source J1518+047 represents a clear example of a young ( $10^3$  yr), but already fading object [14]. In this radio source, only electrons with  $\gamma < 600$  are contributing to the radio emission, while those with higher energies have already faded away. This indicates that in young but fading objects no  $\gamma$ -ray emission is expected.

### 3. The radio luminosity

In terms of radio luminosity CSOs are comparable with the powerful FR II galaxies. From Fig. 1 it is clear that CSOs (x symbols) seem to extend at higher luminosity the correlation between the core luminosity  $L_{\text{core}}$  and the total luminosity  $L_{\text{tot}}$  found for FRI (+ signs), and FR II (asterisks) by [9]. Such high luminosities are expected since CSOs are mainly found at higher redshift, between 0.4 and 2, with only a few objects with  $z \sim 0.1$ .

A remarkable aspect pointed out in Fig. 1 is the presence of 3 CSOs, the radio galaxy OQ 208 and

the radio quasars J0650+6001 and J1415+1320, in the region occupied by the sources, mainly blazars, detected by *Fermi*-LAT during the first three-month observations (diamonds, [1]), making these CSOs good candidate for high energy emission. It is worth noting that another misaligned object, the FRI 3C120, is in the same LBAS region, and it was detected by *Fermi*-LAT in 15-month observations [2].

#### 3.1. The radio galaxy OQ 208

The radio source OQ 208 is associated with a broad-line radio galaxy at redshift  $z=0.076$ . Its radio luminosity is  $\sim 2 \times 10^{44}$  erg/s. It has an asymmetric triple radio structure of 10 pc in size and it is dominated by the western hotspot (Fig. 2). A multi-epoch analysis of the changes of the pc-scale structure has shown that the hotspots are separating with a velocity of  $(0.2 \pm 0.1)c$ , which provides a kinematic age for this source of  $\sim 160 \pm 60$  yr.

A low-surface brightness feature located about 40 mas from the main structure is detected at low

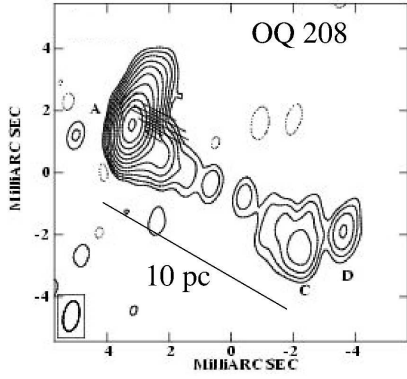


Figure 2: VLBA images at 15 GHz of OQ208. Adapted from [18].

frequencies [11], and it marks the fossil of a previous radio activity that took place a few thousand years before the new episode [13] (Fig. 2). The analysis of the 5 GHz lightcurve from 1987 to 2007 does not show any significant flux density variability (Fig. 3).

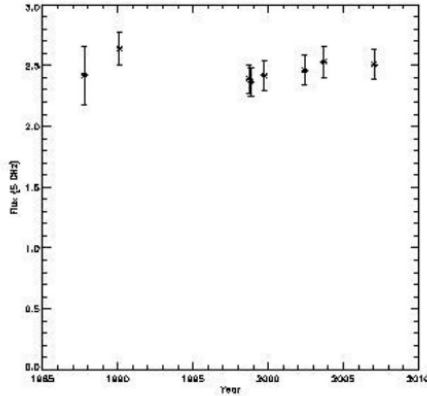


Figure 3: The 5-GHz light curve of OQ208.

### 3.2. The radio quasar J0650+6001

The radio source J0650+6001 is associated with a quasar at redshift  $z=0.455$ . The source is resolved into three components and its radio luminosity is  $\sim 10^{46}$  erg/s. The central component shows a flat spectrum, suggesting the presence of the core, while the two outer regions, with a steeper spectral index, display a highly asymmetric flux density (Fig. 4). Multi-epoch analysis of the changes in the pc-scale structure shows that the outer components are separating with a velocity of  $(0.39 \pm 0.19)c$ , which corresponds to a kinematic age of  $360 \pm 170$  years.

Furthermore, the separation between the core component and the southern hotspot seems to contract with an apparent velocity of  $(0.37 \pm 0.02)c$ . Such contraction is interpreted in terms of a mildly relativistic knot in the jet, still embedded in the central component, that is moving towards the southern component [15]. This interpretation is supported by the detection of some variability related to the central component, as pointed up by the 5-GHz light curve [15].

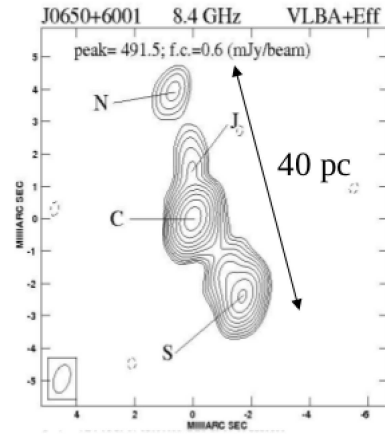


Figure 4: VLBI image at 8.4 GHz of J0650+6001.

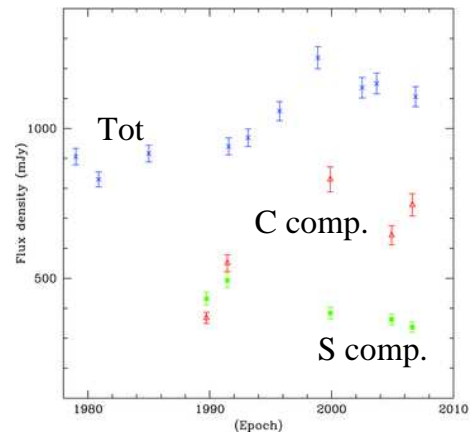


Figure 5: The light curve of J0650+6001 at 5 GHz. Crosses indicate the source flux density from VLA data, while triangles and squares refer to VLBI flux density of component C and S, respectively. Adapted from [15].

## 4. High energy emission in young radio sources

Since CSOs completely reside within the host galaxy, a possible mechanism for producing high energy emission may be the inverse Compton (IC) of thermal UV/IR photons by the lobes' relativistic electrons [19]. Under the assumption of equipartition and assuming that the jet luminosity is  $L_j = 10 \times L_{\text{tot}}$ , and the luminosity provided by the UV photons is  $L_{\text{UV}} = 10^{46} \text{ erg s}^{-1}$ , we compute the expected luminosity at 1 GeV for OQ 208 and J0650+6001 using the formula from [19]:

$$\frac{[\varepsilon L_\varepsilon]_{\text{IC/UV}}}{10^{42} \text{ erg/s}} \sim 2 \left( \frac{\eta_e}{\eta_B} \right) \left( \frac{L_j}{10^{45} \text{ erg/s}} \right)^{1/2} \left( \frac{LS}{100 \text{ pc}} \right)^{-1} \times \left( \frac{L_{\text{UV}}}{10^{46} \text{ erg/s}} \right) \left( \frac{\varepsilon}{1 \text{ GeV}} \right)^{-0.25} \quad (1)$$

or the appropriate IC/UV energy flux:

$$\frac{[\varepsilon S_\varepsilon]_{\text{IC/UV}}}{10^{-12} \text{ erg/cm}^2/\text{s}} \sim 1.6 \times \left( \frac{[\varepsilon L_\varepsilon]_{\text{IC/UV}}}{10^{42} \text{ erg/s}} \right) \left( \frac{d_L}{100 \text{ Mpc}} \right)^{-2}, \quad (2)$$

where  $d_L$  is the luminosity distance to the source,  $LS$  is the source linear size,  $\eta_e/\eta_B$  is the ratio between the particle energy and the magnetic field energy.

By means of Equations 1 and 2, we can compute the expected 1-GeV luminosity and flux density for OQ 208 and J0650+6001, which turn out to be:

- OQ 208:  $L = 2.8 \times 10^{44} \text{ erg s}^{-1}$ ,  $S = 3.8 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ ;
- J0650+6001:  $L = 5 \times 10^{44} \text{ erg s}^{-1}$ ,  $S = 1.2 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$

Assuming standard parameters as above, OQ 208, that is one of the closest CSOs, should have been detected with the sensitivity obtained in one-year observations by *Fermi*, i.e.  $7 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$  at  $5\sigma$  computed assuming a photon index  $\Gamma=2.5$ . The non-detection of the source indicates that the parameters used in the model are too extreme, setting upper limits to the jet power and the amount of UV photons. The high redshift ( $z > 0.4$ ) typical of the majority of young radio sources makes these objects even more difficult to detect. However, in the case of CSOs associated with steep-spectrum quasars, like J0650+6001, where also moderate boosting effects should be present, we can consider an additional contribution of IC made by relativistic electrons from the jet (e.g. [8]).

As *Fermi*-LAT continues to collect data and its sensitivity threshold improves, some young radio sources

may be detected, giving us important information on the physical properties of these objects and the main mechanism responsible for their high energy emission.

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